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Jatropha curcas L.: A crucified plant waiting for resurgence

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ABSTRACT

Jatropha curcas L. (hereinafter Jatropha) is often considered as a magical biodiesel plant with multitude of environmental benefits and therefore, the plantation of Jatropha has been done on a global scale without crop improvement, proper field validation, standardization of agronomic practices and high quality certified planting materials. Importantly, the seed yield and oil content of the species were not validated before the field introduction. Moreover, farmers are not aware of the biology and ecology of Jatropha and even not aware of the pest incidence and common diseases in Jatropha. As a result, there was a total mismatch between the expectations as well as the real performance of this species under field condition. Therefore, the present article is aimed to critically analyze the actual reasons behind the failure of Jatropha in field conditions and recommend suitable strategies for the future utilization of this plant for sustainable biofuel program.

Contents

1. Introduction

Jatropha is a tropical oil bearing plant widely recognized as a potential feedstock for biodiesel production [1–10]. It is native to Mexico and Central America and distributed in Latin America, Africa, India and South East Asia [2–5]. The plant is well adapted to arid and semi-arid climatic conditions and can grow in different type of lands including marginal, degraded and contaminated lands [14]. The multiple attributes and biodiesel production potential of Jatropha have been extensively covered in various literatures [1–23]. Moreover, the prospects and promises of Jatropha biodiesel program in various countries have been reported by many researchers [22,24–28]. Because of its envisioned environmental benefits, large scale plantations of Jatropha have been done in Asian (especially in India and China), African and Latin American countries [23,24]. Irrespective of the geographical context, the cultivation and popularization of Jatropha in above regions have been mooted by three important ethos such as (i) achieving energy security, (ii) revitalizing marginal and degraded lands (commonly called as wastelands) and (iii) alleviating rural poverty through employment and sustainable biofuel production (Fig. 1) [1,29,30]. For the purpose of this

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discourse, a sustainable biofuel production program can be defined as a program that not only provides a continuous and steady supply of biodiesel but also contributes substantially for the ecological, economic and societal development through waste land reclamation, managing local biodiversity, soil quality improvement, job creation and providing entrepreneurial opportunities.

A Scopus based literature survey (http://www.scopus.com) shows that more than 180 reviews on Jatropha has already been published in various research journals. As in the case of other research outlets, RSER has also paid considerable attention to Jatropha and this can be evidenced from the fact that more than 21 reviews on Jatropha has been recently appeared in RSER (Table 1). In fact the reviews covered a wide spectrum of topics such as the general, socio-economic, environmental and sustainability aspects of Jatropha cultivation [2,31–35]; comparative studies on the performance evaluation of Jatropha biodiesel [36–38]; biotechnological approaches for improving Jatropha

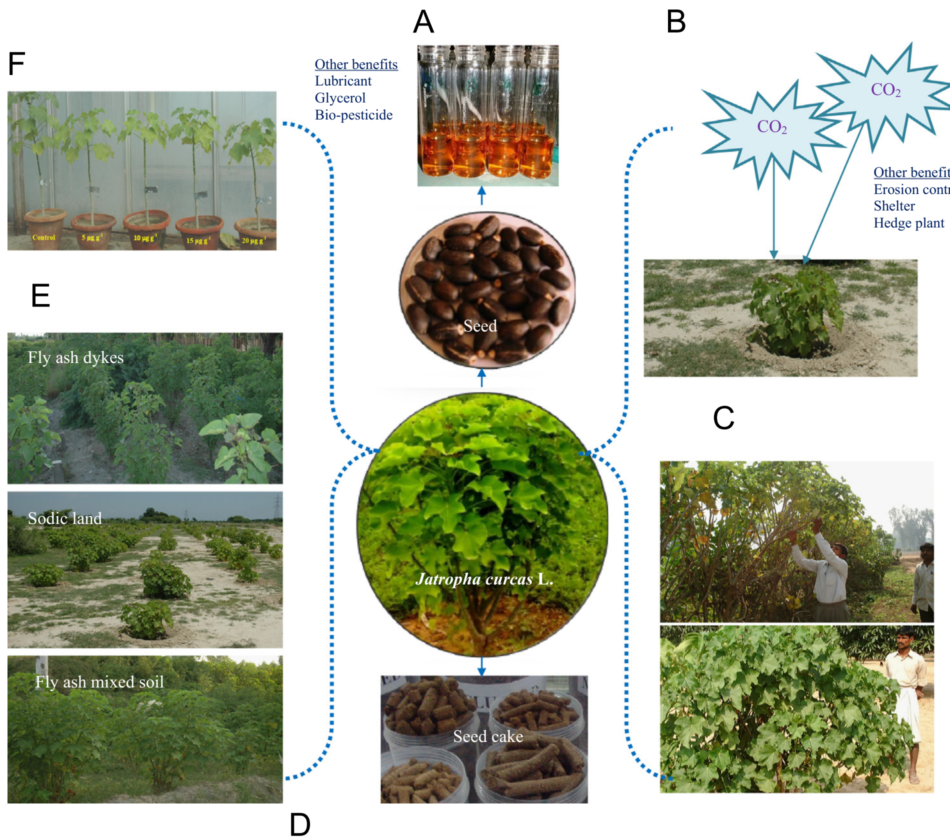

Fig. 1. Multiple attributes of Jatropha suitable for a sustainable biodiesel program. (A) Biodiesel production, (B) Soil carbon sequestration, (C) Rural income and employment generation, (D) Seed cake can be used as a biofertilizer and for biogas production, (E) Restoration and management of wastelands/ degraded lands and (F) Phytoremediation of pesticide.

Table 1
Latest publications on Jatropha published in renewable and sustainable energy reviews.

Sl. no.	Title/topic of the review	Year	Ref
1	*Jatropha curcas*: a ten year story from hope to despair	2014	[24]
2	Global experience with Jatropha cultivation for bioenergy: an assessment of socio-economic and environmental aspects	2014	[31]
3	Comparative studies on performance evaluation of DI diesel engine with high grade low heat rejection combustion chamber with carbureted alcohols and crude Jatropha oil	2014	[39]
4	Performance evaluation of medium grade low heat rejection diesel engine with carbureted methanol and crude Jatropha oil	2014	[40]
5	*Jatropha curcas* as a renewable source for bio-fuels – a review	2013	[32]
6	A Jatropha biomass as renewable materials for biocomposites and its applications	2013	[43]
7	Status of molecular breeding for improving *Jatropha curcas* and biodiesel	2013	[41]
8	A global comparative review of biodiesel production from Jatropha *curcas* using different homogeneous acid and alkaline catalysts: study of physical and chemical properties	2013	[33]
9	Land availability of Jatropha production in Malaysia	2012	[49]
10	Prospects of biodiesel from Jatropha in Malaysia	2012	[48]
11	*Jatropha curcas*: a potential biofuel plant for sustainable environmental development	2012	[34]
12	Review and prospects of Jatropha biodiesel industry in China	2012	[44]
13	Risk management for *Jatropha curcas* based biodiesel industry of Panzhihua Prefecture in Southwest China	2012	[45]
14	Sustainability issues for promotion of Jatropha biodiesel in Indian scenario: a review	2012	[45]
15	A review of biodiesel production from *Jatropha curcas* L. oil	2011	[35]
16	Comparison of palm oil, *Jatropha curcas* and *Calophyllum inophyllum* for biodiesel: a review	2011	[38]
17	Life cycle assessment of biodiesel from soybean, Jatropha and microalgae in China conditions	2011	[46]
18	A review on prospect of *Jatropha curcas* for biodiesel in Indonesia	2011	[33]
19	Applications of biotechnology and biochemical engineering for the improvement of Jatropha and Biodiesel: a review	2011	[42]
20	Biodiesel production from *Jatropha curcas* oil	2010	[36]
21	Prospects of biodiesel from Jatropha in India: a review	2010	[46]

[39,40]; Jatropha biomass as renewable materials for biocomposites [41]; as well as the status of Jatropha cultivation in major cultivating countries such as China [42–44], India [45,46] Malaysia [47,48] and Indonesia [33].

However few recent publications pointed out the underperformance of Jatropha in field conditions and questioned the sustainability of Jatropha-based biofuel program [24,29,30]. We also agree with the general criticism that Jatropha has been overemphasized as a magical plant for global energy crisis; however, we wish to clearly make a point that the stakeholders are being continuously projecting the multiple environmental benefits of this small plant based on the envisioned benefits rather than the field performance and validation. Even scientific and technological investments for crop improvement have not been done so far. As a result, we could see the extraordinary collapse of Jatropha as a global biofuel [30]. However, before condemning this plant based on the field failures, we must try to improve this species according to our aspirations and expectations. Therefore, in the present article, we intended to have a retrospective on Jatropha and recommend future perspectives for the meaningful utilization of Jatropha for sustainable biofuel initiatives. Although the failure of Jatropha has been directly implicated to the lack of standardized agrotechnologies and crop breeding programs, unfortunately the social, ecological and policy reasons behind the failure of Jatropha cultivation have yet to be explored. Here we discuss these issues one by one.

2. Facts and fallacies

The major attributes proclaimed for the wide scale adoption of Jatropha in developing countries were (i) its biodiesel production potential, (ii) higher oil content than other biofuel crops (the seeds of Jatropha contain 40–60% of oil) [36–38,49], (iii) rapid growth, (iv) easy propagation, (v) drought tolerant nature, (vi) ability to grow and reclaim various kinds of land such as degraded, marginal, sodic, alkaline, contaminated etc., (vii) plants can grow without much irrigation and agricultural inputs, (viii) pest resistance, (ix) small gestation periods and (x) suitable traits for easy harvesting such as optimum plant size and architecture [1,8,2–11]. Because of its perceived social, economic and environmental benefits (Fig. 1), researchers and policy-makers in developing countries have shown a keen interest in pursuing Jatropha biofuel program [50–53]. As a result more than 1,000,000 ha of Jatropha plantations have been done in various parts of the world. Among this, 85% of Jatropha cultivation is in Asian countries (including India, China and Myanmar) followed by 12% in Africa and 2% in Latin America (in Brazil and Mexico). India is a leader in Jatropha cultivation and having Jatropha plantations in an area of about 300,000 ha [29,54–57].

Although large scale plantations of Jatropha has been done in various agro-climatic regions of the world, the growth performance, seed yield and oil content of the plant were far below than the expected [11,12,29,58,59]. An expected seed yield of 4–5 mg ha^{-1} yr^{-1} was considered to be commercially viable for a Jatropha-based biofuel program and an average seed yield of 3.75 mg ha^{-1} yr^{-1} with an oil content of 30–35% and oil yield of 1.2 mg ha^{-1} yr^{-1} is better than the yield profile of other important oil seed crops such as soybeans and rapeseed [24]. However, the actual seed yield reported from various countries like India (0.5–1.4 mg ha^{-1} yr^{-1}), Belgium (<0.5 mg ha^{-1} yr^{-1}), South Africa (0.35 mg ha^{-1} yr^{-1}) and Tanzania (2 mg ha^{-1} yr^{-1}) [30] was less than the expected level [60–66].

In reality, there was a significant difference found in the expected and actual seed and oil yield of Jatropha and this mismatch was mainly due to the underperformance of Jatropha in field conditions and also due to the erroneous calculation of seed and oil yield per unit area. The seed yield per unit area (hectare or acre) was mainly calculated on the basis of the yield of individual plants growing in isolation or under experimental trials multiplied with the total number of plants that can be planted in a unit area under a given spacing pattern (i.e. 1×1 m^2 or 1.5×1.5 m^3). The percentage of oil content of the selected seeds collected from wild Jatropha growing in the arid and semi-arid regions of North India is presented in Fig. 2. For this, we have randomly identified 38 mother trees in the study area and the seed samples were collected from selected trees for testing the oil content. Based on the percentage of oil content, the collected accessions were grouped into three major groups such as (i) accessions having $<30\%$ oil content (Group 1), (ii) accessions having 30–34% oil content (Group 2) and (iii) superior accessions or accessions having 34–42% oil content (Group 3). As from Fig. 2, it is very clear that 10 accessions were found under Group 1 category (average oil content) where as 12 accessions were grouped in Group 2 (medium level oil content) and 16 accessions in Group 3 (higher oil content). Among the various accessions, JA-5-06 showed maximum oil content (42.13%) followed by JA-7-06 (41.89%). Although the growth and yield of the species were verified under experimental field trials, the performance of these accessions under varying agro-climatic conditions has not been validated yet [67]. However, we have not studied the quality of the oil from above

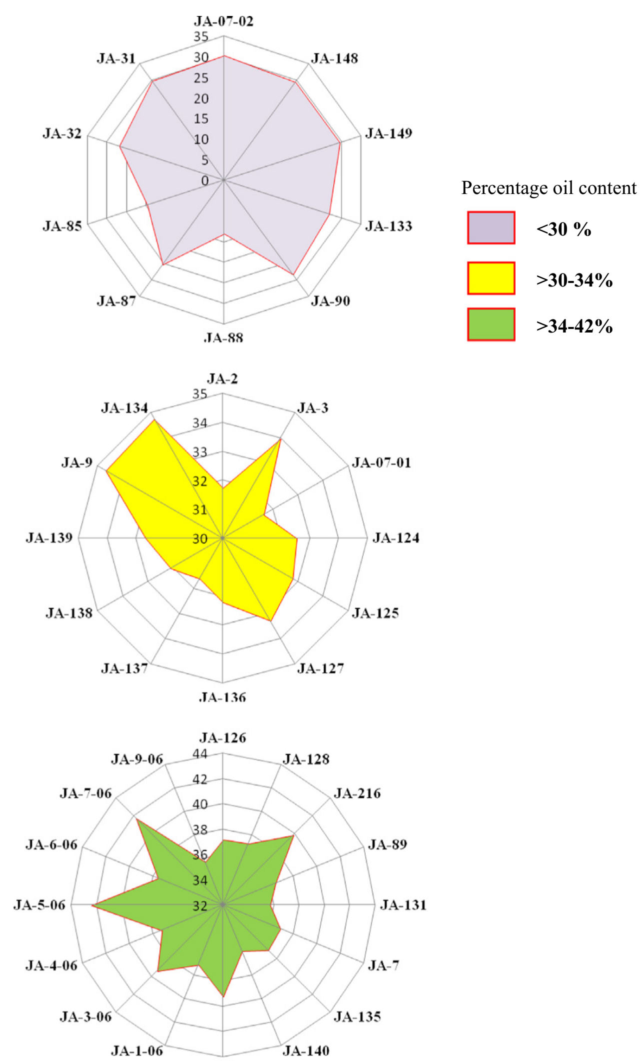

Fig. 2. Seed yield and oil content are the major decisive factors affecting the economics of biofuel program. Jatropha accessions (JA) showing varying percentages of oil content collected from different agroclimatic zones of India (not published).

accessions. Therefore, such studies are very essential for identifying the elite or superior accessions for further exploitations.

Moreover, our own experimental trials proved that Jatropha can survive in sodic and fly ash mixed soil and even in fly ash dykes and can improve the soil carbon pool [67–71] and soil properties through rapid growth and enhanced litter turnover (Fig. 3). Moreover, we have tested the phytoremediation potential of Jatropha against heavy metals and lindane and recommended the strategies for improving the phytoremediation efficiency through molecular approaches [20,71–73]. However, additional conformation regarding the soil restoration and carbon sequestration efficiency of Jatropha plantations is required from diverse edaphic and agro-meteorological conditions. Additionally, the impact of Jatropha plantations on various lands as well as their impact on local biodiversity including microbial biodiversity should be studied in detail [74–79].

Previous studies proved that the quantity and quality of oil content depend upon the Jatropha species and also depend upon the edaphic and climatic conditions. According to Sabandar et al. [80], the genus 'Jatropha' comprises of about 170 species of small trees, shrubs, subshrubs or herbs widely distributed in the Old and New World tropics. The common species in Jatropha genes are *J. curcas* L., *J. chevalieri* Beille, *J. elliptica* Muell. Arg., *J. gaumeri* Greenm., *J. glandulifera* Roxb., *J. gossypiifolia* L., *J. grossidentata* Pax et. Hoffm., *J. integerrima* Jacq., *J. macrantha*, *J. mahafalensis* Jum and H. Perrier, *J. multifida* L., *J. nana* Dalz, *J. podagrica* Hook, *J. pohliana* Muell. Arg., *J. tanjorensis* Ellis and Saroja, *J. unicostata* and *J. weddelliana* Baillon. However, there is no detailed report on the seed and oil yield of majority of these species. Importantly, such species having better traits can be used for the crop improvement program of Jatropha. For instance, Makkar et al. [81] reported that local communities in Mexico consume *Jatropha platyphylla* seeds after roasting. Interestingly, the kernels of *J. platyphylla* contained ca. 60% oil and were free of phorbol esters. Similarly, Sonnleitner et al. [82] evaluated the properties and suitability of *Jatropha mahafalensis* Jum. and H. Perrier; an indigenous and endemic representative of the Jatropha genus in Madagascar. The mean oil content in the various samples ranged from 36% to 55% [83]. Apart from the species difference, the growth, seed and oil yield and oil quality of Jatropha also depend upon the soil conditions [68]. Srivastava et al. [68] reported that the growth, yield traits and oil content of the selected accessions of Jatropha differed in different plantation sites. Furthermore, the study of Singh et al. [60] clearly indicated that yield performance during the multi-locational trials of Jatropha mainly depends upon the soil type and agronomic practices.

It was commonly believed that Jatropha is resistant to pest and diseases. However, field studies revealed that Jatropha is prone to

Fig. 3. The dry matter turnover in Jatropha plantations. (A) Jatropha plantations planted in a $1 \times 1\ m^2$ spacing and (B) the close-up view of the stem and dry matter. The Jatropha plantations can modify the soil properties including soil carbon pool through litter turnover and root exudation [67–71].

Fig. 4. Disease incidence in Jatropha. Like other crops, Jatropha is also prone to various pests and diseases. The photographs (A and B) show viral incidence in Jatropha.

viral disease (e.g., Jatropha mosaic virus) (Fig. 4) and insect attacks. Field studies reported that pest infestation due to leaf miner (*Stomphastis thraustica*), the leaf and stem miner (*Pempelia morosalis*), shield-backed bug (*Calidea panaethiopica*) and fruit sucking predators (*Scutellera perplexa,* and *Maconellicoccus hirsutus*) caused more than 60–80% crop damage in various countries [83–87].

Apart from the above discussed issues, the success of any biofuel mission also depends upon the national level polices for biofuels. In this context, many Asian countries have developed their own national agenda for the wide scale adoption of biofuels based on their energy demand and existing energy usage pattern [27]. For example, in Indonesia, the major emphasis is given to the bioenergy production from palm oils and secondary preference is given to Jatropha-based biofuel program [27]. Similar to the case of Indonesia, the Malaysian government also gives much priority to oil seeds for biofuel production. The Malaysian Government started a palm oil biodiesel program in 1982 and targeted to the use of a B5 (5% processed palm oil and 95% diesel) blend for vehicles and industrial sectors [87]. However, in the case of Thailand, the Government has been looking into the prospects of both biodiesel and ethanol as a substitute for conventional fuels [88]. In China, more emphasis is given to ethanol rather than biofuel production [87]. Regarding the policy front, Government of India has also adopted suitable measures for the promotion, popularization and usage of biofuels particularly biodiesel from Jatropha in the country. Even the Planning Commission, Government of India has also projected Jatropha as candidate species for biofuel program. However, as pointed out by Biswas et al. [14], the policy failed to address the major challenges in Jatropha cultivation such as (i) identifying suitable mother plants for further propagation, (ii) developing high quality planting materials (seeds/cuttings), (iii) identification of suitable lands for Jatropha cultivation, (iv) stakeholder involvement, (v) collection and processing of seeds,

Fig. 5. Superior accessions having high seed and oil yield, and mass multiplication strategies are essential for the commercial cultivation of Jatropha. Photographs A–F show the flowering to various stages of fruit development and G–J show mass multiplication of Jatropha under field conditions.

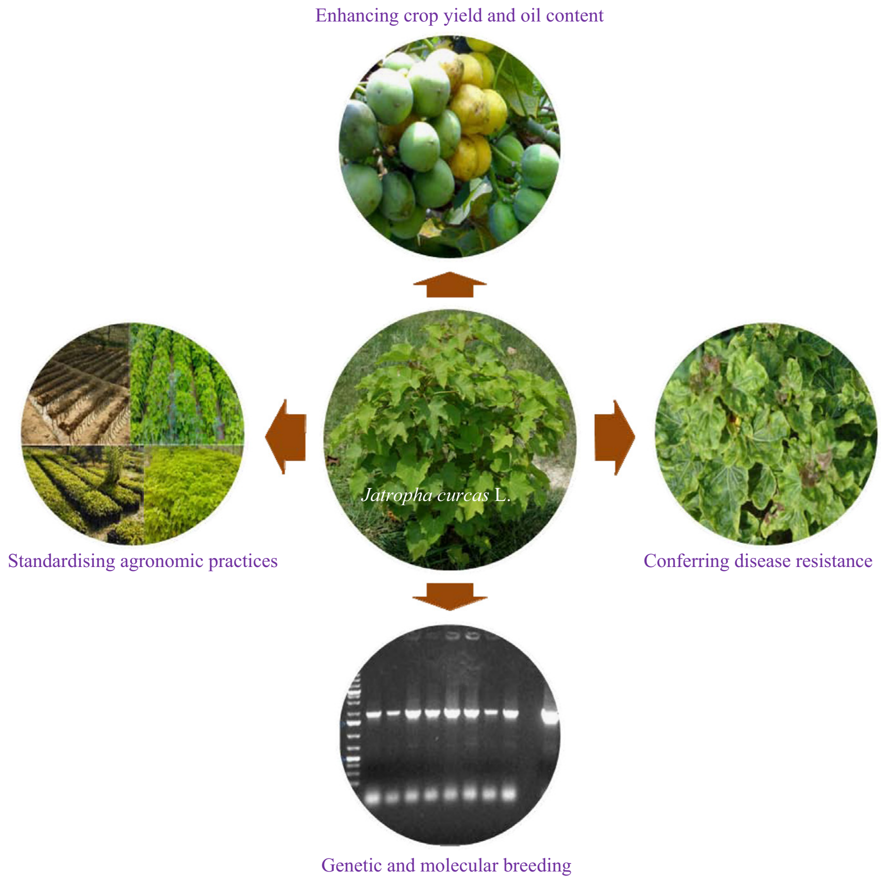

Fig. 6. Strategies for improving the multipurpose benefits of Jatropha.

(vi) oil extraction, transesterification and production of biodiesel, (vii) transportation and storage of biodiesel, (viii) market prize of biofules, and (ix) selling of biofules. Most importantly, the national level biofuel polcies of the major Jatropha producing countries failed to address the social, ecological and economic impacts of jatropha based biorefineries. Most importantly, biofuel polices failed to address the land ownership issues regarding biofuel cultivation in common and community lands and providing incentives or insurance for biofuel cultivation.

3. Reasons behind the field failures of Jatropha

One of the most common wrong notions regarding Jatropha is that the plant needs only minimal inputs and it can grow well in marginal and degraded lands (nutrient poor soils). However, the previous studies clearly show that Jatropha needs considerable inputs. It is true, since time immemorial, the domestication of crop plants has not happened without any inputs and agronomic practices. Even the crops such as rice and wheat, the products of thousands of years of agricultural domestication, cannot perform without standardized agronomic packages. Therefore, it is foolish to believe that a comparatively younger plant in the human history of domestication can grow very well in nutrient deprived soils and even without any additional inputs. This justification is also applicable to the seed yield and oil content of the plant.

The lack of knowledge of farmers on this new species is another serious issue impeding the optimization of standard agronomic practises. Since Jatropha is an exotic species, the farmers are not truly aware of the biology, ecology and the physiology of Jatropha. Therefore, they do not have much knowledge on the growth pattern, nutrient requirement, pest incidence etc. of this species. So it is very essential to educate farmers regarding the cultivation and agronomic practices of Jatropha for varying agro-ecological conditions.

Thirdly, many developing countries including India had officially recommended the large scale cultivation of Jatropha without proper field validation, agronomic practices and certified planting materials or seeds. Perhaps, we do consider this flawed process as the most serious issue which tampered the reputation of Jatropha as a biofuel. Even the governmental agencies or policy makers do not sought the possibility of international collaboration for crop improvement (for increasing the seed and oil yield, biotic and abiotic stress tolerance, the collection of elite germplasms from various agro-climatic regions of the world and for optimizing agrotechnologies). Moreover, the policymakers failed to address the conflict of food versus biofuel production or demarked suitable lands for crop production. Importantly, the biofuel production chain was missing in most of the national policies. Therefore, before completely ignoring this species, we should rethink and admit the failures as a policy failure rather than the crop failure and must immediately start an internationally coordinated crop improvement program for maximizing the multipurpose benefits of Jatropha for a sustainable biofuel program.

4. Recommendations and future perspectives

As we discussed earlier [1], there are number of traits that could be targeted for crop improvement. In fact, the crop improvement can be done in a cordial way by the collaboration of major Jatropha cultivators like India, China, Malaysia, Indonesia, Brazil,

Mexico, South Africa etc. The R&D expertise and the lessons learned by these countries during last several years on Jatropha cultivation can be shared and used for designing genetic and molecular breeding strategies. The collaboration and cooperation of major national and international petroleum or biofuel companies could also seek for this venture. Molecular breeding should be primarily targeted to increase the seed yield, oil content, drought tolerance, abiotic stress tolerance, pest and disease resistance and also for developing optimum sized varieties for easy harvesting and management. The presence of toxic substances like curcin and phorbol esters from the seed of Jatropha should be removed through pathway and biochemical engineering.

The germplasms or accessions from diverse agroclimatic regions of the world must be collected for identifying the superior traits and the better accessions should be used for crop improvement program. Similarly, simplified protocols for the mass multiplication of Jatropha should be developed and transferred to the stakeholders for mass propagation (Fig. 5). The government can also open centres for distributing certified planting materials and provide insurance for covering crop loss due to any uneven event. Similarly, 'Farmers Centres' should be open or it can be attached with the existing nodal centres (for e.g., KVK Centres in India) (Krishi Vigyan Kendra; Centre for Agricultural Sciences) to train farmers about the standard cultivation practices of Jatropha. Before the commercialization, new varieties having improved traits should be raised and tested in different agro-climatic regions of the world. Similarly, agronomic practises for Jatropha for each and every agro-climatic region should be standardized (Fig. 6). The concerned authorities/governmental bodies should also identify suitable lands for the large scale field adoption of Jatropha and it should not happen at the cost of food prodcution. Therefore, utmost care should be taken to define the land types for Jatropha plantations and the land selection/acquisition should not affect the livelihood of local peoples. Moreover, the conflict of interest if any should be resolved before using community and private lands for Jatropha production. The authorities should also ensure the proper market and supply chain of Jatropha biofuel program and should implement decentralized collection, processing, storage and transportation facilities of Jatropha seed and biodiesel.

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